

AN EVALUATION OF MECHANICAL PROPERTIES AND MICROSTRUCTURE OF NITINOL BY FRICTION WELDING

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ABSTRACT

In this research paper, the study of friction welding is being performed on the superelastic Nitinol bar. Nickel - Titanium alloy is also known as Nitinol ($Ni_{50}Ti_{50}$) of 8mm diameter, 50 mm in length on one side and 80mm in length on other side was used as experimental material. Nitinol was joined by using direct drive rotary friction welding machine with 6 tons capacity with fully automated mode was used in joining process. Tensile strength of friction welded 8mm diameter NITINOL joints were investigated considering various process parameters: friction force (F), upset force (U), burn off length and Spindle speed (N). Direct and interaction effects of process parameters on responses were studied by plotting graphs. Micro structural study of base Nitinol and friction welded Nitinol was examined. The results of tensile tests on the processed welded Nitinol indicated a slight increase in strength in the processed regions; likely because of grain size refinement and no decrease in ductility compared to the parent Nitinol material. This research has shown that in term of hardness, the weld metal has the highest hardness followed by HAZ and base metal.

KEYWORDS: Nitinol, Friction Welding, Friction Force, Spindle Speed & Burn Off Length

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INTRODUCTION

Friction welding is a solid state welding process in which the work pieces are joined by the heat generated due to the friction at the interface of the two work pieces. Dissimilar metals can be welded easily. In direct drive friction welding, the most preferred process types, heat is generated in the welding zone by rotating one work piece against the other one at constant or varying speed with an axial pressure for a predetermined period of time [1]. It was known that thermo mechanical behaviour at the interface is critical to the quality of weld. The heat generated in friction welding is depending on coefficient of friction, friction pressure, part rotating speed, and diameter of work piece [2]. Coefficient of friction is a function of friction pressure and rubbing speed, and varies with the diameter of work piece and time.

The predetermined value of heat generated by friction and pressure into surface of joined metals give results in binding of the surface of atoms when they close together during plastic deformation as a product of upsetting of welded element contact boundary. Metallic bonds occurred by interaction between the neighbouring atomic planes of the crystal lattice of metals being welded sufficiently close enough to each other and undergone plastic strain in HAZ of a friction welded joint [3].

The combination of short processing times and the development of the heat directed at the interface results in fairly narrow heat-affected zones, also caused by upsetting a portion of the interface out of the weld joint during the process [4]. The minimal width of the heat-affected zone means that, in general, there is no need for heat treating the parts before or after joining to relieve internal stresses. Also problems like local cracking or reduced corrosion resistance in the heat-affected zone can be avoided or reduced. No filler metal or flux is used.

For the experimental work the heat treated and cold rolled Ni rich Nitinol material was taken because, Cold-working gives higher yield strength, but it destroys the shape memory effect and pseudo elasticity as random dislocations by permanently deforming the detwinned structure, reducing the latent heat of transformation and broadening the temperatures at which transformation occurs. Therefore, cold-working is generally coupled with heat treatment to increase toughness as well as to “restore” the memory effect of removing some of the lattice strain [5] [6]. For all the studied samples, A_f temperature is within the range of -5° to $+5^\circ\text{C}$. From the literature, it is observed that the Ni content increases results in decreasing the austenite finishing temperature [7]. Nitinol is having good electrical and mechanical properties such as high recoverable strain, high strength, long fatigue life, high corrosion resistance.

EXPERIMENTAL DETAILS

Material

The material used in this work super elastic Nickel-Titanium (Nitinol) alloy having the chemical composition is listed in Table 1. Nitinol material is added with various alloying elements to alter transformation temperature greatly. Various properties of Nitinol alloy are presented in Table 2.

Table 1: Chemical Composition of Nitinol Alloy

Elements	Ti	Ni	Co	Cu	Cr	Fe	Nb	C	H	O	N
Amount of wt. in %	44.111	55.78	0.0050	0.005	0.005	0.012	0.005	0.040	0.001	0.035	0.001

Table 2: Properties of Nitinol Alloy

Parameters	Tensile Strength MPa	Yield Strength MPa	Elongation [%]	A_f Temp. $^\circ\text{C}$
Values	750	200	11	$(-5)\pm 5$

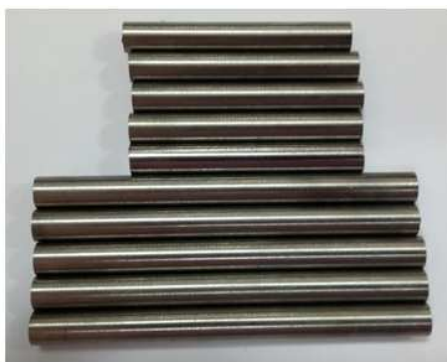


Figure 1: Super Elastic Nitinol Sample

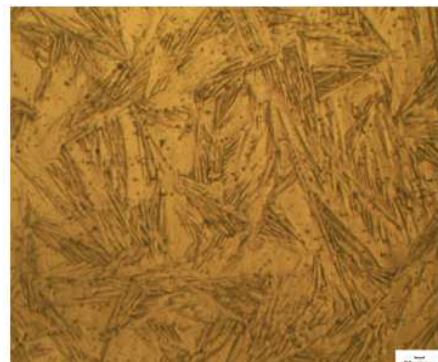


Figure 2: Microstructure of Nitinol Sample

The super elastic Nitinol bar was procured from SMA Wire India, Gujarat as shown in Figure 1. The microstructure of Nitinol sample consists of a plate like alpha phase and grain boundary precipitation of beta inter metallic particles as shown in Figure 2.

EXPERIMENTAL METHOD

The material used for friction welding process is super elastic Nitinol ($\text{Ni}_{56}\text{Ti}_{44}$) alloy. The continuous(direct) drive rotary friction welding machine with 6 tons capacity was employed for joining. Two symmetrical work pieces with the dimensions of 8mm dia, 50mm and 80 mm length were taken. During friction welding the following parameters were considered: upset force as 2.1 tones, upset time as 1 sec, soft force as 0.3 tones, soft force time as 2.5 sec, friction force as 1 ton and friction burn off length as 6mm is kept constant and varied spindle speed. Reading was recorded at 1800,1900 & 2000 rpm respectively. A visual inspection of weld quality was done based on the shape of the bead formed around the outside perimeter of the weld. The friction welded samples with flash is shown in Figure 3. The flash is completely removed by conventional machining process as shown in the Figure 4, which in turn removes surface oxides and other impurities and enhances the properties of the weld. The microstructure, micro hardness and tensile strength were observed for trial and tabulated in Table 3.

Table 3: Experimental Reading for Friction Welding Trials

Sl. No	Spindle Speed (rpm)	Total Burn-off Length (mm)	Actual Upset Burn Off Length (mm)	Actual Friction Time (sec)	Actual Welding Time (sec)	Actual Cycle Time (sec)	Spindle Torque (Nm)	Micro Hardness Reading (Hv)	Tensile Strength (MPa)
1	1800	10.21	4.21	2.6	5.33	104.1	1.646	311	644.58
2	1900	10.40	4.4	3.2	5.92	73.1	2.122	318	691.72
3	2000	10.58	4.58	4.3	7.07	61.8	1.717	330	786.62

PROCESS PARAMETERS

The following parameters were considered during the friction welding process. The input variables are heating pressure (HP), heating time (HT), upsetting pressure (UP), upsetting time (UT) and output variables are Flash width (FW), flash height (FH) and flash thickness (FT) respectively. In order to process the good quality of the joint, these parameters have to be optimized. There are three important types of forces, mainly depend on the yield strength of the material.

- **Soft force** is applied to plane the surface.
- **Friction force** is applied to heat the material.
- **Upset force** is applied for joining the components.

The welding was carried out successfully and the welded samples were subjected to various tests such as micro structural analysis with high resolution Optical Metallurgical Microscopes, micro hardness test using Micro vickers hardness tester and tensile strength using Universal Testing Machine. In Micro structural analysis, the junctures were cut in the transverse weld, embedded in an array of Bakelite, polished and examined in the region of the interfaces of base and weld under an optical metallurgical microscope and whereas in micro hardness test, the test samples were highly polished to enable measuring the size of the impressions. A square base pyramid shaped diamond is used for testing in the Vickers scale. In tensile test, machined welded specimens were subjected to tensile tests. The tensile strength is found to be increased with the increase in spindle force due to the microstructure refinement in the welded region compared to base region, hence higher strength in the weld and specimen is found broken outside the welded region as shown in Figure 5. The parameters chosen for friction welding process are tabulated in Table 4

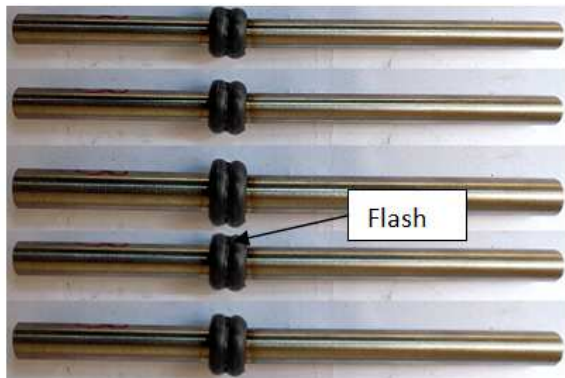


Figure 3: Nitinol Samples After Welding



Figure 4: Nitinol Sample After Machining Process



Figure 5: Nitinol Samples After Tensile Test

Table 4: Process Parameter for Friction Welding

Process Parameters	Values
Friction force	20kg/mm ²
Upsetting force	40kg/mm ²
Burn-off length	10-12 mm
Spindle speed	1800-2000 rmp

RESULTS AND DISCUSSIONS

The Optimization of Process Parameters for Friction Welding are as Follows

Weld Time

With the clear indication from the Figure 6, as the spindle speed increase, weld time was found to be increased due to the increase in burn off length, the higher the burn off length, the higher is the weld time [8].

Total Burn Off

The Figure 7 indicates that, with the increase in spindle speed, the burn off was found to be increased due to the increase in load acting on the specimen, higher the load acting, the higher is the burn off length [9].

Actual Upset Burn Off

It is clear from the Figure 8, with the increase in spindle speed, the actual upset burn off was found to be increased due to the increase in axial forging forces acting on the specimen, higher the axial force, the higher is the upset burn off [10].

Actual Cycle Time

It is clear from the Figure 9 with an increase in spindle speed, the actual cycle time was found to be decreased due to the increase in friction force, hence higher the friction force, lower is the cycle time [11].

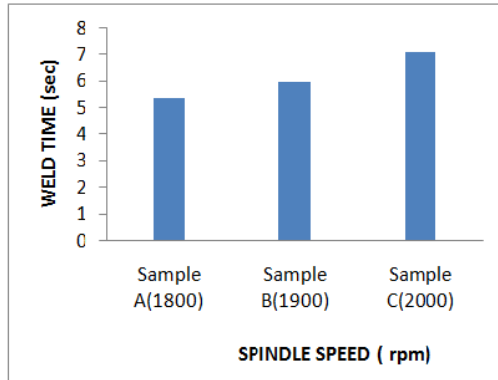


Figure 6: Weld Time V/S Spindle Speed

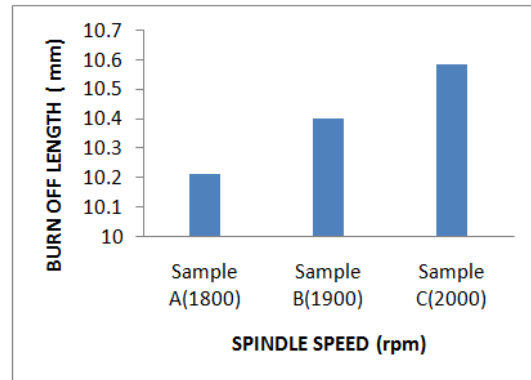


Figure 7: Burn Off Length V/S Spindle Speed

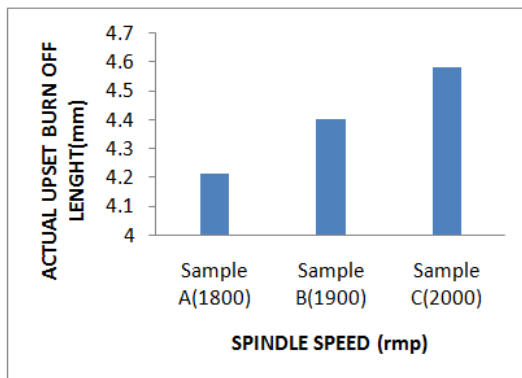


Figure 8: Actual Upset Burn off V/S Spindle Speed

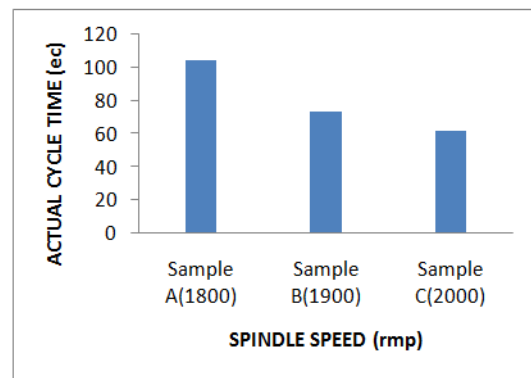


Figure 9: Actual Cycle Time V/S Spindle Speed

Microstructure Image of Nitinol before and after Welding at Different Spindle Speed

Figure 10 shows the micro structural image of Nitinol base (a) and Nitinol friction welded region (b, c, d) at 1800, 1900, 2000 rpm respectively. Figure10 (a) shows that the base metal consists of coarse grains with clearly visible twins. In the present study, the spindle speeds selected are 1800rpm, 1900rpm, and 2000rpm. As spindle force is the one of the important Friction Welding process parameter. Spindle force determines the amount of plasticized material.

Figure 10 (b, c, d) shows increase in re crystallized fine grains due to the increase heat generation. The welded region is subjected plastic deformation hence the microstructure shows more grain refinement occurred in the weld compared to base material, and that the grain size decreased with increase in spindle force. With the increase in the spindle force ultrafine grained microstructure was obtained and the twins were not observed like the base metal [12], [13].

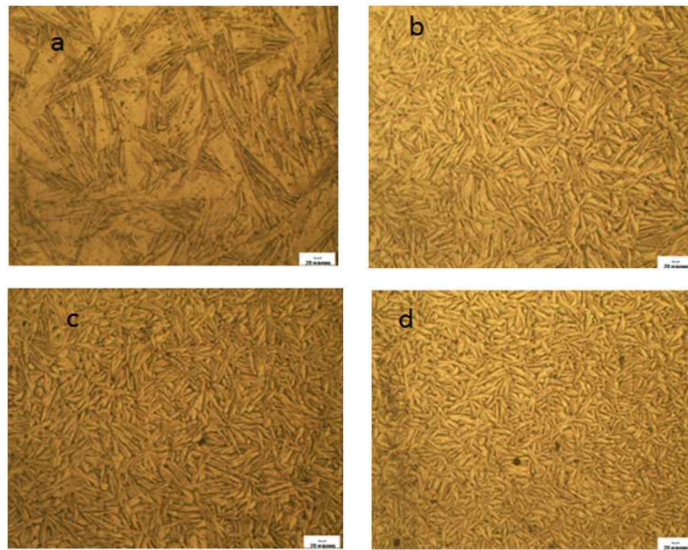


Figure 10: Microstructure of a) Nitinol Base Region (b) Nitinol Welded Region (1800 Rpm) (c) Nitinol Welded Region (1900 Rpm) & (d) Nitinol Welded Region (2000 Rpm)

Micro Hardness Test

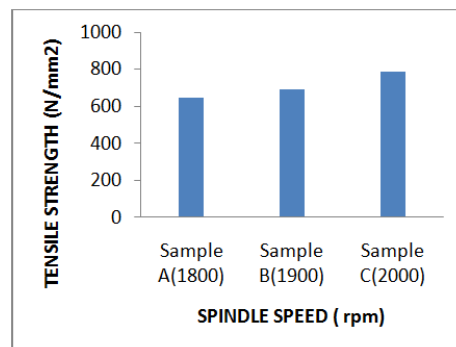
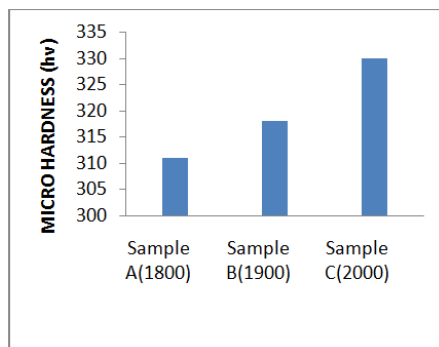


Figure 11: Micro Hardness V/S Spindle Speed Figure 12: Tensile Strength V/S Spindle Speed

It is clear from the Figure 11 that the hardness of the base Nitinol material was found to be 290 HV. After friction welding the hardness of the welded region was found to increase when compared to the base material due to the increase in spindle speed, the mechanical work of the friction welding process increases which promotes grain refining and consequent increase of resistance [14].

Tensile Test

It is clear from Figure 12 that, with the increase in spindle speed, the tensile strength is found to be increased due to the microstructure refinement in the welded region compared to other region, hence the higher strength in the weld specimen is found broken outside the welded region [12,13] [15]

CONCLUSIONS

The friction welded joint of Ni56Ti44 was investigated based on the experimental results.

- As Spindle Force increases, weld time, burn off length, actual upset burn off was found to be increased.

- With the increase in the spindle speed, more grain refinement occurs in the weld compared to base material, ultrafine grained microstructure is obtained and the twins were not observed like the base region.
- Hardness was found to be increased with the increase in spindle force due to the increase in the mechanical work of the friction welding process which promotes grain refining and consequent increase of resistance.
- The tensile strength is found to be increased with the increase in spindle force due to the microstructure refinement in the welded region compared to base region, hence higher strength in the weld and specimen is found broken outside the welded region.

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